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POWER SPECTRUM CLASSIFIER.(U)

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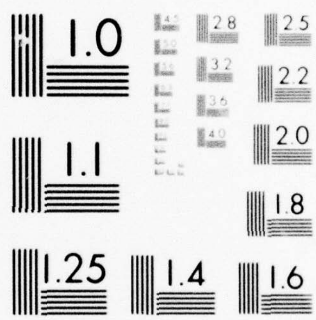

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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FINAL TECHNICAL NOTE

POWER SPECTRUM CLASSIFIER

SEI Reference 5010 • 30 December 1974
Revised 18 March 1975

Prepared for

U. S. Army Mobility Equipment Research and Development Center
Fort Belvoir, Virginia

Submitted in lieu of

Contract No. DAAK02-73-C-0121
Data Item No. A004

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Approved by:

Kenneth H. Miller

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C O N T E N T S

I L L U S T R A T I O N S

ILLUSTRATIONS (Cont.)

I. INTRODUCTION

1.1 OBJECTIVE

SCOPE Electronics Inc. has produced one target classifier under the REMBASS program, U. S. Army Contract No. DAAK02-73-C-0121, SEI Job No. 5010. The purpose of the program was to design and build advanced development models of a pattern recognition set capable of detecting and classifying vehicle targets based on principles developed at SEI under previous Army contracts. These targets fall into two basic areas: aircraft and ground vehicles. Further classification is done within these two classes into tracked versus wheeled ground vehicles, and rotary versus fixed wing aircraft. Figure 1 is the overall block diagram for the target classifier.

1.2 RESULTS

The techniques of data gathering, decision making and classifier design have been demonstrated successfully against a large tape-recorded data base including multi-site data. Two taped-data demonstrations were carried out, the first with a breadboard system, the second with the ADM system using 60 Hz, 110V power. A field data gathering operation was carried out and a new set of reference patterns developed from it during November 1974 using the SEI system. The new reference patterns were demonstrated in the field at EPG, Fort Belvoir, Virginia in December 1974. Performance was good, and is documented in this report.

Software and signal study aspects of this program were highly successful, including the selection of features and the structure of the algorithms.

Hardware development for battery-operated field deployment was not successfully completed.

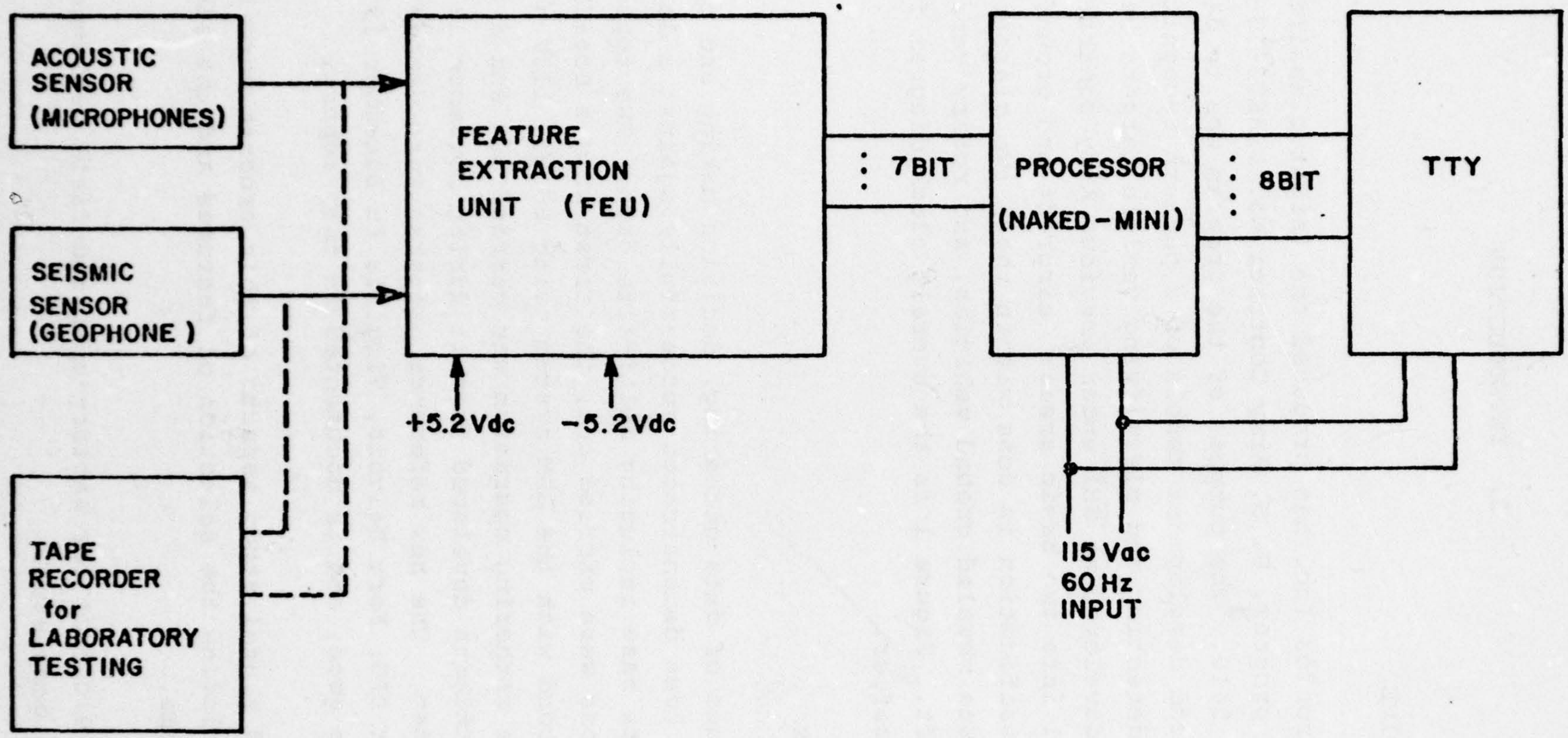

Figure 1. Overall Block Diagram, Target Classifier

1.3 PROGRAM DESCRIPTION

Both acoustic and seismic sensors are employed in this classifier. Signals from these sensors are processed and digitized in the Feature Extraction Unit (FEU). The FEU separates the signal energy into frequency bands which are detected and smoothed. These detected channels are time-division multiplexed, digitized, and delivered to the processor as 7-bit digital words.

The processor is a Computer Automation "Naked-Mini" LSI minicomputer, selected for its small size and ability to be repackaged as well as for its computing speed and capacity.

The minicomputer performs the pattern classification task by computing the similarity of the detected signals to statistically defined characteristics of the vehicle classes of interest. The known signal class statistics are stored in the minicomputer. Decisions are recorded by the minicomputer on a peripheral teletypewriter, as follows:

DECISION	DESIGNATION
Unknown Target Detected	0
Tracked Vehicle	1
Wheeled Vehicle	2
Rotary Wing Aircraft	3
Fixed Wing Aircraft	4
Ground Vehicle	5
Aircraft	6

The decision function algorithm is a decision tree using quadratic classifiers at each of three binary decision nodes.

The design of this system was based upon empirically derived statistics of signals from instrumentation tape recordings. These tape recordings were primarily made at the following sites:

Rome Air Development Center, New York
Fort Bragg, North Carolina
Aberdeen Proving Ground, Maryland
Fort Belvoir, Virginia
Yuma, Arizona
Warren, Michigan

Results of a previous feasibility effort showed that data statistics are very site-dependent and that a robust classifier design must be based on multi-site data.

The taped data presented certain difficulties, in that the instrumentation introduced dynamic range and, occasionally, noise problems. However, test results based upon playing tape recorded data against classifier designs based on the statistics of taped data showed good classification accuracy. When the system was deployed in the field, it was found that the taped data upon which the classifier parameters were based did not adequately represent the target signatures as observed directly through the sensors, and performance was unsatisfactory. Fortunately, a method had been developed earlier for punched-paper-tape recording data directly from the FEU digitizer. Using this capability, it is now possible to quickly acquire a new data base in the field, to maintain and increase a digital library of data, and to develop new sets of classifier coefficients based upon improved data bases.

The goal of this contract was to produce four battery-operated, field-deployable classifier units. The nature of the signal statistics and characteristics is such that a significant amount of computation is required to make accurate decisions. Two hardware approaches to field deployment were discussed prior to undertaking this effort. The first approach recommended was to use a microprocessor, which had the advantages of small size, weight and power consumption. This approach also had some disadvantage in terms of the risk involved in using new technology. The second and chosen approach was to transfer the processing from the

Raytheon 704 minicomputer used in feasibility demonstrations to a conventional minicomputer which could be stripped down and repackaged in a field-deployable configuration. The hardware problems with this approach were primarily associated with power consumption, with packaging being a secondary problem. Measures were taken to reduce power consumption by extremely tight power specifications on that portion of the circuitry which was always on (detection, analog front end, and interface with the minicomputer), and by a design which turned the computer on only for brief intervals when it was time to make a decision. The computing time requirement was a duty cycle of about 400 milliseconds every 10 seconds, or 4%. While the average power requirement under this approach is quite satisfactory, peak current loads at low voltage from the batteries will still present a problem.

The state of the project upon delivery is that the software and analysis tasks have been successfully completed and demonstrated, and a single working system has been demonstrated in the field. Battery operation was not achieved, however. The delivered unit operates off 60 Hz power mains. The Computer Automation minicomputer is operating off its internal power supplies, while the Feature Extraction Unit operates from ± 5.2 volts dc derived from laboratory power supplies.

The decision at the proposal stage of this program was made in favor of a stripped minicomputer as opposed to the alternative microprocessor approach. This decision was based upon higher cost and risk estimates made at that time for microprocessors as compared to minicomputers. If the same program were to be undertaken at the present time, the microprocessor approach now appears to be the more attractive of the two, and would have a high probability of success. Since the beginning of the Power Spectral Classifier effort, SEI has employed microprocessors in both quadratic classifier and control applications with good results.

Since the power problems remaining in the present design are still difficult, and since the first field tests have already been completed, it is recommended that means be found to prove the feasibility of the Power Spectral Classifier System with the available ac-powered unit. If the results are successful, it is recommended that the Army proceed to engineering development of a system using a low-cost off-the-shelf microprocessor system to implement the Power Spectral Classifier using SEI's quadratic classifier design.

The Feature Extraction Unit is housed in a rugged waterproof container capable of withstanding immersion in one foot of water. Its computer, a Computer Automation Alpha LSI, is packaged in a standard commercial configuration. Units will not be damaged by normal handling and transport.

The geophone used is a Geospace GSC-20D (8 Hz, 400 ohms). The geophone is connected to the electronics by means of a waterproof, shielded and strain-relieved connector and cable approximately 20 meters in length.

The microphone is a Sonotone B13725 having frequency response from 20 Hz to 9 kHz, and is compatible with the requirements for extracting chosen target discriminants. It is appropriately housed in a ruggedized cavity to withstand specified field environments in the presence of rain, wind, and other adverse conditions without physical damage or significant degradation of performance. It is also fitted with a windscreen to cut down on response from wind pressure variations. The microphone assembly cable is approximately 20 meters in length.

II. CIRCUIT DESCRIPTION

2.1 FEATURE EXTRACTION UNIT

The Feature Extraction Unit hardware processes analog inputs from the microphone and seismic sensor and generates digital output words for processing by the Computer Automation minicomputer. The digital words represent a power spectrum analysis of the incoming signal. The energy is divided into frequency cells and a sequence of digital words is generated indicating the amount of energy in each frequency cell.

Figure 2 is a block diagram of the Feature Extraction Unit. Each sensor output, seismic or acoustic, is amplified and bandwidth limited in the input bandpass filter. The signal is amplitude stabilized in the AGC amplifier and then divided into frequency cells in the filter bank. The seismic signal is divided into 2 cells, while the acoustic signal is divided into 12 cells between 20 and 300 Hz. Each filter output is peak detected and integrated producing a dc level representing the amount of energy in that particular frequency band.

The signals are sequentially sampled by the multiplexer. The multiplexer is a 16 input commutator which monitors the 14 frequency cells, the seismic zero-crossing rate and acoustic zero-crossing rate. These zero-crossing rate signals are an indication of the average frequency in the input signal.

Each of the 16 channel outputs is sampled and held long enough for an analog-to-digital conversion to be made. This digital number is presented to the data bus of the Computer Automation minicomputer.

In addition to the basic signal processing circuitry, the hardware contains timing and control circuitry. A power level detector

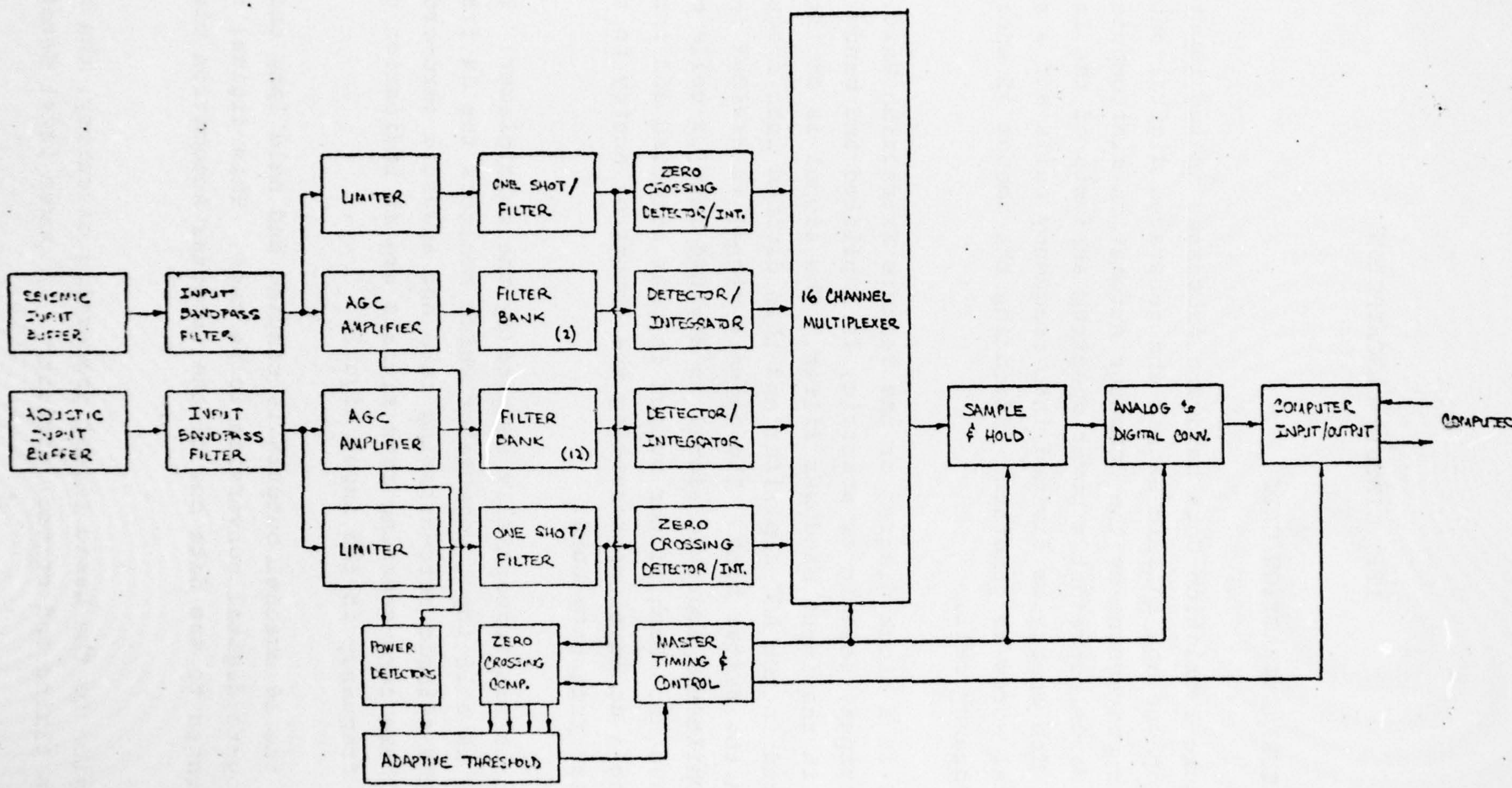

Figure 2. Feature Extraction Unit Block Diagram

analyzes the agc control voltage and determines if a change in the background power level has occurred. Zero-crossing comparators monitor the background frequency. "Target detector" is an OR function of these two conditions. A power or frequency change will trigger the target detector. Once the target detector has been triggered, the rest of the timing and control for the minicomputer is activated. The unit then cycles — on for one second, off for nine seconds — until the target is lost. During the one-second process time, the system commutates through the 16 signals, performs the classification algorithm, announces its decision and then shuts off until the next system initiate has been generated.

2.2 DECISION TREE LOGIC

2.2.1 Introduction

Digitized representations of the seismic and acoustic features will be input to the digital subsystem, implemented on a Computer Automation Naked-Mini LSI processor. The function of the digital subsystem is to utilize these inputs to detect and identify the seven classes of vehicles cited earlier:

- target
- tracked vehicles
- wheeled vehicles
- helicopters
- fixed wing aircraft
- ground vehicles
- air vehicles

Key aspects of the decision algorithm which effect these identifications include:

- Tree structure organization for flexible, sequential decision making.
- Use of quadratic processors at each node.
- Post-decision logic to increase classification accuracy, reduce false alarm rate, and reduce processor duty cycle.

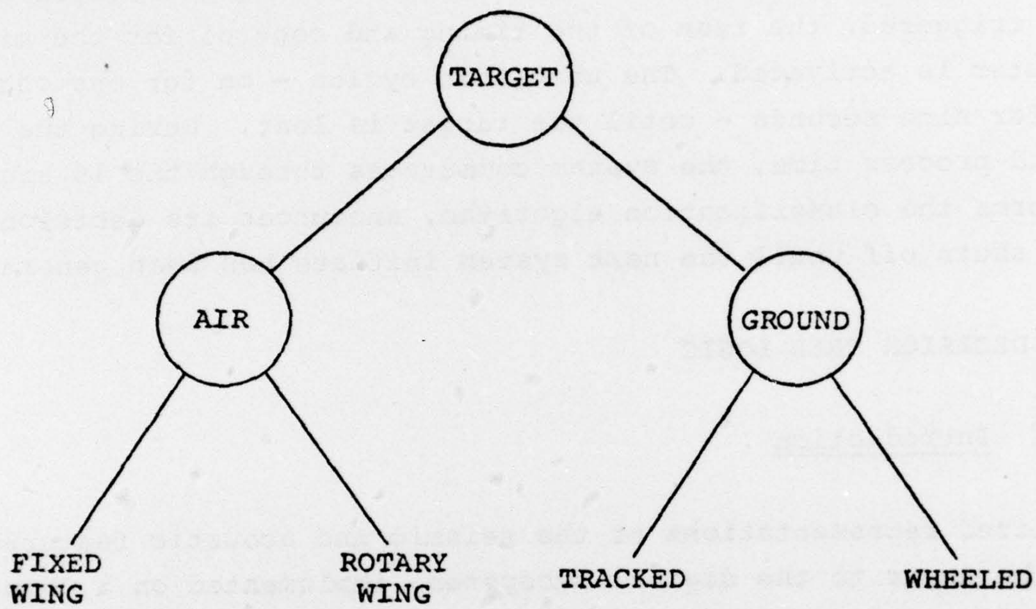

Figure 3. Power Spectrum Classifier

2.2.2 Decision Tree

The implementation of the recognition system utilizes a multi-level decision tree structure. See Figure 3. Such a tree-structure approach to sequential decision making has numerous advantages, such as the following:

- The tree structure may be matched to the clustering properties of the problem at hand. This will prevent multimodal classes from degrading system performance.
- The approach is amenable to extremely flexible and modular design techniques, as will be discussed in this section.
- At each step in the decision process, we are partitioning the event space into subclasses, eliminating some classes from further consideration. Further, each decision is of reduced order, thus increasing the classification accuracy to be expected.

2.2.3 Decision Function

The quadratic node implements its decision by operating on a set of input features in a nonlinear way to produce an output value which describes the similarity between the unknown input and each possible class. The class corresponding to the best match is then selected, subject to certain threshold constraints. If the set of input features is arranged in an n-dimensional vector $\underline{X}$, the nonlinear operator is given by

$$g_i = \underline{X}^T A_i \underline{X} + \underline{B}_i^T \underline{X} + C_i \qquad (1)$$

where i ranges over the number of classes involved. A_i is an N×N matrix, $\underline{B}$ is an N×1 vector, and C is a scalar. As has been demonstrated, a Bayes or minimum-risk classifier may, under some common assumptions, be simplified to the above form, where:

$$A_i = -K_i^{-1}$$ the inverse of the covariance for class i (2)

$$\underline{B}_i = 2K_i^{-1}\underline{M}_i$$ where M_i is the mean vector for class i (3)

and $$C_i = -M_i^T K_i^{-1} M_i$$ (4)

Although the above terms look rather complex, they are precomputed and need only be stored digitally or as resistor weights in the final implementation of the quadratic node. In fact, using the above relations, Equation 1 may be simplified to:

$$g_i = -(\underline{X}-M_i)^T K_i^{-1}(\underline{X}-\underline{M}_i) \tag{5}$$

where it is manifest that only the mean vector $\underline{M}_i$ and the inverse covariance matrix K_i^{-1} need to be stored for each class. If $\underline{X}$ is an N-dimensional matrix, this means that N(N+1) values must be stored for each class. The price which must be paid for the increased power of the quadratic function over the linear version now becomes clear. As the number of input features increases, the complexity of the quadratic node increases quadratically while that of the less powerful linear classifier increases linearly. This obviously puts a premium on the efficient use of features.

III. SIGNAL STUDIES AND LEARN DEVELOPMENT

The classifier learn was developed as follows. An analog evaluation data base was selected from Michigan, Fort Bragg and RADC sites, and included a variety of speeds, ranges, and at least two vehicles from each class. It is known that variations from site to site have adverse effects on classifiers, so a large data base was considered essential.

Data bases were digitized for training and evaluation of the final algorithm. These data were developed through the front-end Feature Extraction Unit, and consist of an even distribution of:

- ranges
- vehicles
- sites
- speeds

Figures 4a through 4d are lists of tapes and vehicle runs that were used in developing the classifier learn. The size of the learn data base was approximately 200 samples, with each vehicle "run" contributing from 6 to 20 samples depending upon the speed of the vehicle and its signal strength.

Figures 5a through 5c provide a summary of the learn evaluation, which was obtained by playing tapes from Fort Bragg, Michigan and RADC into the classifier. Each tape was played from beginning to end, so it is estimated that the learn data base comprised about 50% of the evaluation data base. One class of vehicle, the five-ton-truck class, has been deleted from this summary. These vehicles had a classification accuracy of only 40% (60% of the time they were called "tracks"). These data have not been investigated sufficiently to determine the reason for the poor performance. It could be a problem of insufficient five-ton-truck samples in the learn, or simply that five-ton trucks "sound" like tracks in the measurement space. In compiling this learn evalua-

tion, two complete passes were made through all tapes, one on 9/13/74 (Figure 5a) and one on 10/2/74 (Figure 5b). (The learn itself was finalized on 9/11/74, and combined results are shown in Figure 5c.) Appendix A provides a run-by-run summary of the results; it can be seen that, although the decisions on a given run on 9/13/74 might be different than for the same run on 10/2/74, the overall cumulative scores remained rather stable.

On a "run by run" basis, the classifier results are equally encouraging, since in the course of most vehicle runs, the classifier makes 5 to 15 decisions. Typical examples of such runs are shown in Figures 6a through 6e. Note that on a given run there may be classification errors, such as on tape Bragg 3, Run 4 (Figure 6a). The two and one-half ton truck is incorrectly classified as a fixed wing aircraft and a tracked vehicle in two of the ten decisions. On the basis of all decisions, however, including six wheeled, one ground vehicle, and one target, it is highly improbable that the target is anything but a wheeled vehicle. Similarly, on tape Michigan 34, Run 1 (Figure 6c), the helicopter is incorrectly called a wheeled vehicle twice and a ground vehicle once. On a run basis, however, it is clearly a rotary-wing aircraft, since it is called rotary wing seven times and aircraft once.

TAPE/RUN	VEHICLE/CLASS	SPEED	TAPE FOOTAGE	START MARKER	END MARKER
Bragg 3					
1	M35A2/2	22	83	70	120
4	"	31	390	130	70
9	M151/2	6	1048	85	105
12	"	16	1912	110	80
16	"	22	2533	110	80
20	"	31	3002	120	80
Bragg 7					
5	M35A2/2	6	495	90	110
9	"	16	1768	90	115
21	M114/1	6	3005	75	110
Bragg 19					
2	M114/1	22	120	125	80
3	M114/1	25	380	90	120
Bragg 31					
1	M577/1	16	108	90	120
5	M577/1	22	1012	80	115
9	M577/1	25	1784	80	120
Bragg 52					
1	APC/1	16	101	60	110

Figure 4a. Power Spectrum Classifier, Learn Development Data Base, 9/11/74

TAPE/RUN	VEHICLE/CLASS	SPEED	TAPE FOOTAGE	START MARKER	END MARKER
Michigan					
M16					
1	M113/1	16	78	50	20
4	"	22	820	20	50
8	"	31	1610	20	50
19	M106A/1	6	2958	15	50
M30					
1	M48/1	16	100	60	40
2	"	22	330	10	50
M39					
1	M35A2/2	6	12	10	40
4	"	6	1510	100	20
8	"	22	2454	100	20
12	"	31	3280	70	10
M43					
3	M151/2	6	245	10	40
7	"	16	2220	20	40
11	"	22	3175	10	40
M45					
3	M54/2	6	170	50	20
4	"	16	628	20	40
9	"	22	1845	10	60
14	"	31	2858	60	10

Figure 4b. Power Spectrum Classifier, Learn Development Data Base, 9/11/74

TAPE/RUN	VEHICLE/CLASS	SPEED	TAPE FOOTAGE	START MARKER	END MARKER
Michigan					
M34					
1	HELO/3	60	25	Start and stop determined by ear. Listened to audio track.	
2	"	60	140		
3	"	90	300		
4	"	90	390		
5	"	60	490		
7	"	90	760		
10	"	60	1290		
11	"	90	1425		
13	"	90	1640		
14	"	90	1750		

Figure 4c. Power Spectrum Classifier,
Learn Development Data Base, 9/11/74

TAPE/RUN	VEHICLE/CLASS	SPEED	TAPE FOOTAGE	START MARKER	END MARKER
RADC-1					
2	KC135/4	200	512	Use target detector to turn on. Turn off manually.	
4	"	"	716		
5	"	"	867		
6	"	"	1012		
7	"	"	1155		
8	"	"	1303		
9	"	"	1451		
10	"	"	1589		
11	"	"	1743		
12	"	"	1885		
13	"	"	2044		
14	"	"	2182		
RADC-2					
5	C131/4	160	692		
6	"	"	795		
7	"	"	867		
8	"	"	938		
10	"	"	1063		
11	"	"	1171		
12	"	"	1231		
13	"	"	1322		
14	"	"	1391		
16	"	"	1505		
17	"	"	1570		
18	"	"	1631		
19	"	"	1708		
20	"	"	1794		
21	"	"	1894		
22	"	"	1983		
23	"	"	2060		
24	"	"	2153		

Figure 4d. Power Spectrum Classifier, Learn Development Data Base, 9/11/74

TARGET	# OF RUNS	NUMBER OF RUNS WITH DETECTION	NUMBER OF RUNS WITH MAJ. 2 CLASS CORRECT	NUMBER OF RUNS WITH MAJ. 4 CLASS CORRECT	PERCENT RUNS WITH DETECTION	PERCENT RUNS MAJ. 2 CLASS CORRECT	PERCENT RUNS MAJ. 4 CLASS CORRECT	DATE
2.5 ton	49	49	47	27	100	96	55	9/13/74
truck	49	49	44	26	100	90	53	10/02/74
5 ton	11	11	11	0	100	100	0	9/16/74
truck	12	12	10	1	100	83	8	10/02/74
APC	28	28	28	19	100	100	68	9/13, 9/19/74
	25	25	25	20	100	100	80	10/02/74
C131	29	29	24	22	100	83	76	9/20/74
	29	29	26	23	100	90	79	10/03/74
Helicop-	14	14	14	14	100	100	100	9/16/74
ter	14	14	14	13	100	100	93	10/03/74
Jeep	39	39	31	30	100	79	77	9/13, 9/16, 9/19/74
	38	38	31	25	100	82	66	10/02/74
KC135	12	12	11	11	100	92	92	9/16/74
	13	13	13	12	100	100	92	10/03/74
M106A	1	1	1	1	100	100	100	9/13/74
	1	1	1	1	100	100	100	10/02/74
M48	5	5	3	2	100	60	40	9/13/74
Tank	5	5	3	2	100	60	40	10/02/74
M577	12	12	12	12	100	100	100	9/13/74
Howitzer	13	13	13	12	100	100	92	10/02074
Overall	200	200	182	138	100	91	69	September
Perform- ance	199	199	180	135	100	90	68	October

Figure 5. Overall Results Based Upon Learn of 9/11/74

RUN	DIRECTION	VEHICLE/CLASS	SPEED	CALLED	LOCATION
1	S-N	2-1/2T/2	22 mph	0	60
				2	70
				2	80
				2	90
				2	CPA
				5	105
				5	110
				2	120
				0	125
				2	130
2	N-S	2-1/2T/2	22 mph	2	135
				2	130
				2	120
				0	
				2	110
				0	
				1	CPA
				0	
				0	90
				2	80
				0	70
4	S-N	2-1/2T/2	31 mph	2	
				2	130
				2	
				4	120
				5	110
				0	CPA
				1	90
				2	80
				2	
				2	70

0 = TARGET, 1 = TRACK, 2 = WHEEL, 3 = ROTARY WING, 4 = FIXED WING, 5 = GROUND VEHICLE, 6 = AIR VEHICLE.

Figure 6a. Power Spectrum Classifier, Learn Evaluation, 9/13/74, Tape Bragg 3

RUN	DIRECTION	VEHICLE/CLASS	SPEED	CALLED	LOCATION
1	N-S	M113/1	16 mph	0	70
				4	
				5	60
				5	
				0	50
				0	
				1	40
				1	
				0	CPA
				0	
				1	20
				1	
				1	10
2	S-N	M113/1	16 mph	0	0
				1	
				1	10
				0	
				0	CPA
				0	
				0	40
				1	50
7	N-S	M113/1	22 mph	0	
				0	90
				0	
				0	
				0	80
				0	
				0	70
				0	
				0	60
				0	
				0	50
				0	40
				1	CPA
				1	
				1	20
				1	10

0 = TARGET, 1 = TRACK, 2 = WHEEL, 3 = ROTARY WING, 4 = FIXED WING, 5 = GROUND VEHICLE, 6 = AIR VEHICLE.

Figure 6b. Power Spectrum Classifier, Learn Evaluation, 9/13/74, Tape Michigan 16

RUN	DIRECTION	VEHICLE/CLASS	SPEED	CALLED	LOCATION
1	--	HELO/3	60 kts	2	
				5	1 km
				3	
				3	
				3	
				3	CPA
				3	
				3	
				3	
				0	
				2	
				6	
2	--	HELO/3	60 kts	3	
				2	
				2	
				3	
				3	RR tracks
				3	
				3	
				3	runway
				0	
				3	CPA
				3	
				3	
4	--	HELO/3	90 kts	3	
				3	
				0	RR tracks
				3	runway
				0	
				0	CPA
				3	

0 = TARGET, 1 = TRACK, 2 = WHEEL, 3 = ROTARY WING, 4 = FIXED WING, 5 = GROUND VEHICLE, 6 = AIR VEHICLE.

Figure 6c. Power Spectrum Classifier, Learn Evaluation, 9/13/74, Tape Michigan 34

RUN	DIRECTION	VEHICLE/CLASS	SPEED	CALLED	LOCATION
2	--	KC135/4	200 kts	4 4 0 1 4 4	CPA
4	--	KC135/4	200 kts	0 0 4 4 4 4	CPA
6	--	KC135/4	200 kts	0 0 0 0 0 4 0 6	CPA
7	--	KC135/4	200 kts	0 0 4 1 4 4	CPA

0 = TARGET, 1 = TRACK, 2 = WHEEL, 3 = ROTARY WING, 4 = FIXED WING, 5 = GROUND VEHICLE, 6 = AIR VEHICLE.

Figure 6d. Power Spectrum Classifier, Learn Evaluation, 9/13/74, Tape RADC 1

RUN	DIRECTION	VEHICLE/CLASS	SPEED	CALLED	LOCATION
5	--	C131/4	160 kts	0 0 6 0 0 0 4 0 0	CPA
6	--	C131/4	160 kts	0 6 0 0 0 4 4 4 4 4 0 0	CPA
7	--	C131/4	160 kts	0 4 0 0 4 4 0 0	CPA

0 = TARGET, 1 = TRACK, 2 = WHEEL, 3 = ROTARY WING, 4 = FIXED WING, 5 = GROUND VEHICLE, 6 = AIR VEHICLE.

Figure 6e. Power Spectrum Classifier, Learn Evaluation, 9/13/74, Tape RADC 2

IV. FIELD TESTS

Field tests for the Power Spectrum Classifier were conducted at Fort Belvoir's Engineering Proving Ground test track. The first test consisted of evaluating the system with the same learn (training data base) that had been used in the laboratory evaluation at SEI, i.e., a learn that had been developed from taped data. In preparing for this test, the following changes were made to the system in an attempt to optimize system performance:

- Differential input lines were incorporated in the input buffers to reduce noise pickup.
- Gains were adjusted to account for the predicted differences in input signals from live targets versus that experienced with taped data.

4.1 TAPE DATA LEARN EVALUATION

In the site setup, an oscilloscope was used to monitor input signals throughout the tests. Two significant differences between "live" data and taped data were noted. First, the seismic signals at Engineering Proving Ground demonstrated considerably more high frequency content than signals monitored from tapes. Secondly, the general level of signals (both acoustic and seismic) appeared to be much higher in a live environment. Test vehicles of the following types were used in the evaluation:

- 1/4 ton trucks (jeeps)
- 2-1/2 ton trucks
- helicopters
- APC
- M48 tanks

The results of these tests revealed that the learn developed from taped data would be insufficient for live targets. Virtually no

VEHICLE	SPEED/ALTITUDE	SAMPLES
M48	7 mph	82
	22 mph	50
APC	7 mph	43
	22 mph	68
2-1/2 ton	7 mph	39
	22 mph	56
jeep	7 mph	55
	22 mph	39
5 ton	7 mph	70
	22 mph	37
helo	500 ft	24
	1000 ft	34
	1500 ft	15
*fixed wing	taped data	250

* These data were kept in the learn from the tape data base.

Figure 7. Data Base for Learn Development, Live Data Taken at EPG, Fort Belvoir

correct classifications were made. Approximately 90% of the decisions printed out were those of "target," while the class decisions themselves were mostly incorrect. It was evident that the tape recorded signatures that were used to develop the learn were not sufficiently representative of actual targets at Fort Belvoir to permit a successful demonstration.

4.2 LIVE DATA LEARN GENERATION

In gathering data for the learn at Fort Belvoir, attempts were made to get representative runs of vehicles as follows:

- jeeps
- 2-1/2 ton trucks
- 5 ton trucks
- APC
- M48 tanks
- helicopters

Ground vehicle data were taken at 7 mph and 22 mph, while the helicopter data were taken at about 60 kts and 1000 ft. Fixed wing aircraft were not available, so no new fixed wing data were taken.

Figure 7 below provides a breakdown of the data samples that were used in creating the final learn.

4.3 LEARN EVALUATION RESULTS, LIVE DATA

The results of the learn evaluation at Fort Belvoir's Engineering Proving Ground are provided in Figure 8. Run-by-run data are provided in Appendix B. The following points should be noted about these data:

- The accuracy of the tracked vehicles is about as high as could be expected, probably because of the large signals they generate compared to other vehicles.

TARGET	NUMBER OF RUNS	NUMBER OF RUNS WITH DETECTION	NUMBER OF RUNS WITH MAJORITY CORRECT CLASS (2 CLASS)	NUMBER OF RUNS WITH MAJORITY CORRECT CLASS (4 CLASS)	PERCENT RUNS WITH 1 DETECTION	PERCENT RUNS MAJORITY CORRECT CLASS (2 CLASS)	PERCENT RUNS MAJ. CORRECT CLASS (4 CLASS)
2-1/2 ton truck	16	16	15	6	100%	94%	38%
5 ton truck	10	10	10	7	100%	100%	70%
APC	10	10	10	10	100%	100%	100%
Jeep	10	10	10	10	100%	100%	100%
M-48	10	10	10	10	100%	100%	100%

Figure 8. EPG Test Results Learn 11/19/74 Tests of 12/09 and 12/10/74

- Wheels, in general, are lower in accuracy, and the errors committed fall into two categories:

  1) There are 20 misclassifications of 2-1/2 ton trucks (called fixed wing or air) in two runs. Both of these runs were at 7 mph, using the same vehicle that gave no air misclassifications in three other runs. These passes are suspect, and similar ones have not been witnessed, even on taped data. Although the cause has not been isolated, it can be explained and virtually eliminated, since the classifier rarely has a problem discriminating at the ground versus air node.

  2) There were altogether 42 instances where wheels were called tracks (39 of these were the larger vehicles like 2-1/2 ton and 5 ton trucks, while 3 were jeeps). This is similar to results seen with taped data, i.e., wheels tend to be called tracks at CPA.

- There were no fixed wing aircraft for evaluation purposes.

- Rotary wing aircraft used in evaluation were significantly different from the one trained on, so results were poor. The system was trained on a small "executive" type helicopter, but evaluation flights were by large UH-1 craft. There was virtually no similarity between the signatures of these two vehicles.

V. CONCLUSIONS

- Data gathering, algorithmic classifier design, feature selection, and decision accuracy have been demonstrated successfully in this program, both against extensive taped data evaluations and against an abbreviated field test. An ac-powered model of the classifier system was delivered. The hardware effort to configure a battery-powered minicomputer ADM system for unsupported field test deployment was not successful.

- Measured classifier performance indicates classification accuracies in the vicinity of 90% to be immediately attainable. As the data base is improved in quality and quantity, it will be possible to improve performance using new reference patterns without changes in algorithm structure. This is done by using more representative data in the calculation of reference patterns.

- In the development of larger and more representative data bases, analog taped data should not be used unless absolutely necessary. Whenever possible, data should be collected in the field using the SEI-developed system with its own sensors. The measured features are punched in digital form on paper tape and then stored permanently in a digital file at SEI. In this form, the data do not degrade and are not subject to calibration problems or variations in playback equipment. They are recorded through the same sensors and front-end equipment for which reference patterns are to be developed. For these reasons, the library is able to grow and improve consistently.

- In particular, the present library requires more data on military helicopters and heavy wheeled vehicles.

- The unit delivered under this contract should be maintained and used to develop a digital library of multi-site signals including several runs per vehicle and many vehicles. Demon-

strations and evaluations should be performed on the system to develop performance statistics on its strengths and weaknesses.

- Engineering development of a new system should be carried forward. The system should be based on a microprocessor using the same logic, classifier structure, sensors, and processor parameters as those in the delivered system. A microprocessor, as opposed to a minicomputer, will reduce size, power requirements, weight, complexity, and cost. Several units should be built for extensive evaluation. Hardware development on the α-16 minicomputer-based system should not be carried on beyond the level of maintenance required for data gathering and evaluation.

Appendix A

DETAILED RESULTS FROM TAPE EVALUATION

In the following pages, the first column is an identification code for information retrieval purposes. The combination of TAPE and RUN specifies the exact location of the recorded run. The vehicle type is abbreviated in the VEH column and the evaluation date is given in the DATE column. LEARN refers to the generation date of the reference patterns under test. The remaining columns, TGT, TRK, WHL, RW, FW, G, and A, list the number of responses of each type output during the run.

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	TAPE	RUN	VEH	DATE	REM1 LEARN	TGT	TRK	WHL	RW	FW	G	A
127	819	7	2,5T	91374	91174	22	0	0	0	0	2	2
231	819	7	2,5T	100274	91174	19	0	2	0	0	4	2
105	819	8	2,5T	91374	91174	9	0	1	0	0	1	2
232	819	8	2,5T	100274	91174	8	0	0	0	0	2	2
109	819	9	2,5T	91374	91174	12	0	0	0	0	4	2
233	819	9	2,5T	100274	91174	12	0	0	0	0	3	2
110	819	10	2,5T	91374	91174	13	1	1	0	0	3	2
234	819	10	2,5T	100274	91174	15	0	1	0	0	3	2
111	819	11	2,5T	91374	91174	10	0	0	0	0	2	2
235	819	11	2,5T	100274	91174	8	0	0	0	0	2	1
112	819	12	2,5T	91374	91174	4	2	0	0	0	2	2
236	819	12	2,5T	100274	91174	3	2	2	0	0	2	2
113	819	13	2,5T	91374	91174	6	0	2	0	0	0	2
237	819	13	2,5T	100274	91174	5	0	0	0	0	0	2
114	819	14	2,5T	91374	91174	7	2	0	0	0	1	2
238	819	14	2,5T	100274	91174	5	0	0	0	0	1	2
115	819	15	2,5T	91374	91174	8	0	0	0	0	1	2
239	819	15	2,5T	100274	91174	6	2	2	0	0	1	2
116	819	16	2,5T	91374	91174	6	0	0	0	0	3	2
240	819	16	2,5T	100274	91174	5	0	0	0	0	2	2
117	819	17	2,5T	91374	91174	3	0	0	0	0	1	2
241	819	17	2,5T	100274	91174	5	0	0	0	0	2	2
55	83	1	2,5T	91374	91174	2	0	7	0	2	2	2
221	83	1	2,5T	100274	91174	2	0	7	0	0	0	2
57	83	2	2,5T	91374	91174	5	1	4	0	0	0	0
222	83	2	2,5T	100274	91174	3	0	2	0	0	1	2
58	83	3	2,5T	91374	91174	9	1	8	0	0	1	2
223	83	3	2,5T	100274	91174	2	1	3	0	0	0	2
59	83	4	2,5T	91374	91174	1	1	6	0	1	1	2
224	83	4	2,5T	100274	91174	1	3	1	0	0	2	2
60	83	5	2,5T	91374	91174	1	2	6	0	0	2	2
225	83	5	2,5T	100274	71174	2	3	1	0	0	0	2
61	83	6	2,5T	91374	91174	1	3	5	0	0	1	2
226	83	6	2,5T	100274	91174	2	2	3	0	2	2	2
227	83	7	2,5T	100274	91174	2	2	2	0	0	2	2
79	87	1	2,5T	91374	91174	4	2	2	0	0	1	2
242	87	1	2,5T	100274	91174	3	2	4	0	0	0	2
80	87	2	2,5T	91374	91174	1	2	3	0	0	0	2
243	87	2	2,5T	100274	91174	2	2	3	0	2	2	2
81	87	3	2,5T	91374	91174	1	2	1	0	2	2	2
244	87	3	2,5T	100274	91174	0	3	1	0	0	0	2
82	87	4	2,5T	91374	91174	2	3	1	0	0	1	2
245	87	4	2,5T	100274	91174	1	3	2	0	0	2	2
83	87	5	2,5T	91374	91174	6	2	2	0	0	0	2
246	87	5	2,5T	100274	91174	5	0	4	0	0	1	2
84	87	6	2,5T	91374	91174	14	2	1	0	0	2	2
247	87	6	2,5T	100274	91174	9	0	0	0	0	2	2
85	87	7	2,5T	91374	91174	7	2	1	0	0	3	2
248	87	7	2,5T	100274	91174	5	1	2	0	0	2	0
86	87	8	2,5T	91374	91174	11	2	2	0	0	1	2
249	87	8	2,5T	100274	91174	4	1	3	0	0	3	2
87	87	9	2,5T	91374	91174	1	1	6	1	0	0	2
250	87	9	2,5T	100274	91174	1	1	9	0	0	6	1
88	87	10	2,5T	91374	91174	1	1	3	0	0	1	1
251	87	10	2,5T	100274	91174	1	1	2	0	1	0	2
89	87	11	2,5T	91374	91174	4	1	1	0	0	3	2

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	TAPE	RUN	VEH	DATE	REM1 LEARN	TGT	TRK	WHL	RW	FW	G	A
255	87	11	2.5T	100274	91174	2	3	1	0	0	0	0
90	87	12	2.5T	91374	91174	7	0	3	0	0	2	0
256	87	12	2.5T	100274	91174	7	0	2	0	0	2	0
91	87	13	2.5T	91374	91174	5	0	1	0	0	0	0
92	87	14	2.5T	91374	91174	6	0	0	0	0	3	0
257	87	14	2.5T	100274	91174	6	0	0	0	0	3	0
93	87	15	2.5T	91374	91174	5	0	0	0	0	1	0
258	87	15	2.5T	100274	91174	4	0	0	0	0	0	0
94	87	16	2.5T	91374	91174	7	0	0	0	0	0	0
259	87	16	2.5T	100274	91174	5	0	0	0	0	2	0
95	87	17	2.5T	91374	91174	1	2	1	0	0	2	1
260	87	17	2.5T	100274	91174	0	1	0	0	0	3	0
96	87	18	2.5T	91374	91174	2	1	4	0	0	1	0
261	87	18	2.5T	100274	91174	2	0	2	0	0	0	0
97	87	19	2.5T	91374	91174	0	2	2	0	0	2	0
262	87	19	2.5T	100274	91174	0	1	1	0	0	2	0
98	87	20	2.5T	91374	91174	1	1	3	0	0	2	0
263	87	20	2.5T	100274	91174	[illegible]	1	2	0	0	1	0
167	439	1	2.5T	91374	91174	10	0	6	0	0	1	0
316	439	1	2.5T	100274	91174	10	0	6	0	0	3	0
168	439	2	2.5T	91374	91174	12	0	2	0	0	0	0
317	439	2	2.5T	100274	91174	8	0	3	0	0	2	0
169	439	3	2.5T	91374	91174	10	0	8	0	0	4	0
318	439	3	2.5T	100274	91174	17	0	4	0	0	2	0
170	439	4	2.5T	91374	91174	6	0	5	0	0	5	0
319	439	4	2.5T	100274	91174	2	0	5	0	0	6	0
171	439	5	2.5T	91374	91174	3	0	3	0	0	2	0
320	439	5	2.5T	100274	91174	3	0	1	0	0	2	0
172	439	6	2.5T	91374	91174	4	0	2	0	0	2	0
321	439	6	2.5T	100274	91174	3	0	2	0	0	1	0
173	439	7	2.5T	91374	91174	5	0	1	0	0	2	0
322	439	7	2.5T	100274	91174	4	0	1	0	0	2	0
174	439	8	2.5T	91374	91174	6	0	4	0	0	1	0
323	439	8	2.5T	100274	91174	6	0	6	0	0	3	0
175	439	9	2.5T	91374	91174	5	0	7	0	0	1	0
324	439	9	2.5T	100274	91174	3	0	3	0	0	4	0
176	439	10	2.5T	91374	91174	11	0	3	0	0	1	0
325	439	10	2.5T	100274	91174	6	0	5	0	0	0	0
177	439	11	2.5T	91374	91174	2	0	2	0	0	2	0
326	439	11	2.5T	100274	91174	2	0	2	0	0	0	0
178	439	12	2.5T	91374	91174	5	0	11	0	0	3	0
327	439	12	2.5T	100274	91174	4	0	5	0	0	1	0
						489	70	237	1	2	114	4
						489						
190	445	1	5 T	91674	91174	6	1	0	0	0	1	0
339	445	1	5 T	100274	91174	9	1	2	0	0	0	0
191	445	3	5 T	91674	91174	12	4	1	0	3	2	1
340	445	3	5 T	100274	91174	3	5	1	2	3	1	2
192	445	4	5 T	91674	91174	3	3	1	0	0	2	0
341	445	4	5 T	100274	91174	7	1	0	2	0	4	0
342	445	5	5 T	100274	91174	10	2	1	0	1	2	0
193	445	6	5 T	91674	91174	5	1	1	0	0	2	0

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	TAPE	RUN	VEH	DATE	REM1 LEARN	TGT	TRK	WHL	RW	FW	G	A
343	M45	6	5 T	100274	91174	5	1	1	0	2	2	2
194	M45	7	5 T	91674	91174	11	1	1	0	1	3	1
344	M45	7	5 T	100274	91174	11	1	2	0	0	3	0
195	M45	8	5 T	91674	91174	7	4	3	0	0	1	2
345	M45	8	5 T	100274	91174	6	4	4	0	0	1	0
196	M45	9	5 T	91674	91174	8	1	0	0	0	0	0
346	M45	9	5 T	100274	91174	8	2	0	0	0	1	2
197	M45	10	5 T	91674	91174	7	3	0	0	4	1	0
347	M45	10	5 T	100274	91174	7	3	2	0	2	1	1
198	M45	12	5 T	91674	91174	7	1	1	0	1	3	1
348	M45	12	5 T	100274	91174	7	1	1	0	2	4	0
199	M45	13	5 T	91674	91174	6	2	0	0	0	0	0
349	M45	13	5 T	100274	91174	6	1	0	0	0	1	2
200	M45	14	5 T	91674	91174	6	3	2	0	2	2	1
350	M45	14	5 T	100274	91174	6	2	2	0	2	2	1
						178	46	18	2	21	39	8
						178						

	TAPE	RUN	VEH	DATE	REM1 LEARN	TGT	TRK	WHL	RW	FW	G	A
121	B19	1	APC	91374	91174	6	0	0	0	0	1	0
122	B19	2	APC	91374	91174	7	5	0	0	1	2	0
226	B19	2	APC	100274	91174	8	4	0	0	0	3	0
123	B19	3	APC	91374	91174	3	4	0	0	0	1	0
227	B19	3	APC	100274	91174	2	4	0	0	0	2	0
124	B19	4	APC	91374	91174	4	5	0	0	0	1	0
228	B19	4	APC	100274	91174	3	4	0	0	0	1	0
125	B19	5	APC	91374	91174	7	2	0	0	0	2	2
229	B19	5	APC	100274	91174	5	4	0	0	0	4	0
126	B19	6	APC	91374	91174	7	5	0	0	0	0	0
230	B19	6	APC	100274	91174	5	4	0	0	0	0	0
130	H52	1	APC	91974	91174	10	1	0	0	1	12	2
264	H52	1	APC	100274	91174	12	0	0	2	1	4	1
131	H52	2	APC	91974	91174	15	0	4	0	1	5	0
265	H52	2	APC	100274	91174	11	0	2	0	0	1	0
132	H52	3	APC	91974	91174	15	0	2	0	0	6	0
266	H52	3	APC	100274	91174	9	0	0	0	2	1	0
133	H52	4	APC	91974	91174	13	0	2	0	3	6	0
267	H52	4	APC	100274	91174	6	0	1	0	1	3	0
99	H7	21	APC	91374	91174	6	3	1	0	0	7	0
100	H7	22	APC	91374	91174	14	3	1	0	0	3	0
145	M16	1	APC	91374	91174	13	5	0	0	1	2	0
324	M16	1	APC	100274	91174	12	7	0	0	2	1	1
146	M16	2	APC	91374	91174	7	3	0	0	0	0	0
325	M16	2	APC	100274	91174	7	4	0	0	0	0	2
147	M16	3	APC	91374	91174	9	7	0	0	0	2	1
326	M16	3	APC	100274	91174	9	3	0	0	1	3	0
148	M16	4	APC	91374	91174	6	1	0	0	0	0	2
327	M16	4	APC	100274	91174	4	1	0	0	0	2	0
149	M16	5	APC	91374	91174	12	1	0	0	1	3	0
328	M16	5	APC	100274	91174	9	3	0	0	1	2	1
150	M16	6	APC	91374	91174	8	0	0	0	2	1	0
329	M16	6	APC	100274	91174	4	1	0	0	0	3	0
151	M16	7	APC	91374	91174	13	4	0	0	0	0	0
310	M16	7	APC	100274	91174	11	4	0	0	1	0	0

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	TAPE	RUN	VEH	DATE	REM1 LEARN	TGT	TRK	WHL	RW	EX	G	A
152	M16	8	APC	91374	91174	4	5	0	0	0	0	0
311	M16	8	APC	100274	91174	1	4	0	0	0	1	0
153	M16	9	APC	91374	91174	9	2	0	0	0	1	0
312	M16	9	APC	100274	91174	9	3	0	0	0	0	0
154	M16	10	APC	91374	91174	5	1	0	0	1	0	0
313	M16	10	APC	100274	91174	5	1	0	0	1	0	0
155	M16	11	APC	91374	91174	10	3	0	0	2	0	0
314	M16	11	APC	100274	91174	7	4	0	0	1	2	2
162	M32	6	APC	91374	91174	3	5	2	0	0	0	0
285	M32	6	APC	100274	91174	1	6	2	0	0	0	0
163	M32	7	APC	91374	91174	22	7	1	0	0	12	0
286	M32	7	APC	100274	91174	17	6	1	0	0	11	0
164	M32	8	APC	91374	91174	24	6	0	0	6	4	1
287	M32	8	APC	100274	91174	17	5	0	0	0	6	0
165	M32	9	APC	91374	91174	6	4	0	0	0	6	0
288	M32	9	APC	100274	91174	9	5	0	0	0	17	0
166	M32	10	APC	91374	91174	22	8	1	0	1	6	0
289	M32	10	APC	100274	91174	21	5	0	0	0	7	0
						486	172	20	0	27	154	5
						486						
225	M19	1	BKGD	100274	91174	9	0	0	0	0	0	0
						9	0	0	0	0	0	0
						9						
27	R2	5	C131	92074	91174	8	0	0	0	1	0	1
364	R2	5	C131	100374	91174	4	0	0	0	1	0	0
28	R2	6	C131	92074	91174	6	0	0	0	4	0	1
365	R2	6	C131	100374	91174	5	0	0	0	1	0	1
29	R2	7	C131	92074	91174	2	0	0	0	3	0	1
366	R2	7	C131	100374	91174	3	0	0	0	1	0	1
30	R2	8	C131	92074	91174	13	0	0	0	2	0	2
367	R2	8	C131	100374	91174	1	0	0	0	4	0	0
31	R2	9	C131	92074	91174	8	0	0	0	2	0	1
368	R2	9	C131	100374	91174	3	0	0	0	2	0	0
32	R2	10	C131	92074	91174	5	0	0	0	1	0	2
369	R2	10	C131	100374	91174	2	0	0	0	2	0	0
33	R2	11	C131	92074	91174	17	0	0	0	1	0	0
370	R2	11	C131	100374	91174	4	0	0	0	1	0	0
34	R2	13	C131	92074	91174	4	0	0	0	2	0	0
372	R2	13	C131	100374	91174	5	0	0	0	0	0	0
35	R2	14	C131	92074	91174	2	0	0	0	0	0	3
373	R2	14	C131	100374	91174	3	0	0	0	0	0	2
36	R2	16	C131	92074	91174	3	0	0	0	2	0	3
375	R2	16	C131	100374	91174	2	0	0	0	3	0	0
37	R2	17	C131	92074	91174	4	0	0	0	0	[illegible]	[illegible]
376	R2	17	C131	100374	91174	3	0	0	0	1	0	0
38	R2	18	C131	92074	91174	2	0	0	0	3	0	[illegible]
377	R2	18	C131	100374	91174	1	0	0	0	3	0	0
39	R2	19	C131	92074	91174	3	0	0	0	2	0	0

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	TAPE	RUN	VEH	DATE	REM1 LEARN	TGT	TRK	WHL	RW	FW	G	A
378	R2	19	C131	100374	91174	2	0	0	0	3	0	0
40	R2	20	C131	92074	91174	4	0	0	0	1	0	0
379	R2	20	C131	100374	91174	5	0	0	0	0	0	0
41	R2	21	C131	92074	91174	11	0	0	0	1	0	2
380	R2	21	C131	100374	91174	3	0	0	0	1	0	1
42	R2	22	C131	92074	91174	6	0	0	0	0	0	7
381	R2	22	C131	100374	91174	5	0	0	0	1	0	2
43	R2	23	C131	92074	91174	9	0	0	0	0	0	1
382	R2	23	C131	100374	91174	4	0	0	0	1	0	1
44	R2	24	C131	92074	91174	5	0	0	0	0	0	0
383	R2	24	C131	100374	91174	4	0	0	0	1	0	0
45	R2	25	C131	92074	91174	4	0	0	1	2	0	0
384	R2	25	C131	100374	91174	3	0	0	1	1	0	2
46	R2	26	C131	92074	91174	5	0	0	0	0	0	0
385	R2	26	C131	100374	91174	5	0	0	0	0	0	0
47	R2	27	C131	92074	91174	12	0	0	0	0	0	0
386	R2	27	C131	100374	91174	4	0	0	0	1	0	0
48	R2	28	C131	92074	91174	12	0	0	0	1	0	0
387	R2	28	C131	100374	91174	5	0	0	0	0	0	7
49	R2	29	C131	92074	91174	4	0	0	0	1	0	0
388	R2	29	C131	100374	91174	3	0	0	0	2	0	0
50	R2	30	C131	92074	91174	4	0	0	0	2	0	0
389	R2	30	C131	100374	91174	4	0	0	0	2	0	2
51	R2	31	C131	92074	91174	3	3	0	0	2	0	1
390	R2	31	C131	100374	91174	2	0	0	0	2	2	1
52	R2	32	C131	92074	91174	5	0	0	0	3	0	1
391	R2	32	C131	100374	91174	3	0	0	0	3	0	0
53	R2	33	C131	92074	91174	3	0	0	0	1	0	1
392	R2	33	C131	100374	91174	4	0	0	0	1	0	7
54	R2	34	C131	92074	91174	4	0	0	0	2	0	0
393	R2	34	C131	100374	91174	5	0	0	0	1	0	2
55	R2	35	C131	92074	91174	3	0	0	0	2	0	1
394	R2	35	C131	100374	91174	3	0	0	0	2	0	1
						273	0	0	2	52	0	30
						273						
1	M34	1	HEL	91674	91174	1	0	2	7	0	0	1
395	M34	1	HEL	100374	91174	1	0	1	8	0	0	0
2	M34	2	HEL	91674	91174	1	0	2	9	0	0	0
396	M34	2	HEL	100374	91174	3	0	1	7	0	0	0
3	M34	3	HEL	91674	91174	4	0	1	2	0	1	0
397	M34	3	HEL	100374	91174	4	0	0	2	0	0	0
4	M34	4	HEL	91674	91174	3	0	0	4	0	0	0
398	M34	4	HEL	100374	91174	3	0	0	4	0	0	0
5	M34	5	HEL	91674	91174	1	0	1	2	0	0	0
399	M34	5	HEL	100374	91174	1	0	1	1	0	0	0
6	M34	6	HEL	91674	91174	1	0	1	3	0	0	0
400	M34	6	HEL	100374	91174	1	0	0	3	0	0	0
7	M34	7	HEL	91674	91174	2	0	0	3	0	0	0
401	M34	7	HEL	100374	91174	3	0	0	9	0	0	0
8	M34	8	HEL	91674	91174	1	0	0	8	1	0	0
402	M34	8	HEL	100374	91174	4	0	0	5	0	0	0
9	M34	9	HEL	91674	91174	3	0	0	2	0	0	3

	TAPE	RUN	VEH	DATE	REM1 LEARN	TGT	TRK	WHL	RW	FW	G	A
403	M34	9	HEL	100374	91174	2	0	0	2	0	0	2
10	M34	10	HEL	91674	91174	1	0	0	9	0	0	1
404	M34	10	HEL	100374	91174	1	0	0	9	0	0	1
11	M34	11	HEL	91674	91174	1	0	0	3	0	0	1
405	M34	11	HEL	100374	91174	1	0	0	2	0	0	1
12	M34	12	HEL	91674	91174	0	0	0	7	0	0	2
406	M34	12	HEL	100374	91174	0	0	0	5	0	0	1
13	M34	13	HEL	91674	91174	0	0	0	6	0	0	2
407	M34	13	HEL	100374	91174	0	0	0	6	0	0	2
14	M34	14	HEL	91674	91174	2	0	0	2	0	0	2
408	M34	14	HEL	100374	91174	1	0	0	2	0	0	2
						46	0	17	132	1	1	9
						46						
62	33	7	JEEP	91374	91174	3	1	4	0	0	1	2
63	33	8	JEEP	91374	91174	14	1	11	1	0	6	1
208	33	8	JEEP	100274	91174	6	1	1	0	0	5	2
64	33	9	JEEP	91374	91174	3	4	9	0	0	0	2
209	33	9	JEEP	100274	91174	2	2	5	0	1	0	2
65	33	10	JEEP	91374	91174	3	3	11	0	0	1	2
210	33	10	JEEP	100274	91174	0	1	7	0	0	2	2
66	33	11	JEEP	91374	91174	9	1	19	0	1	0	2
211	33	11	JEEP	100274	91174	5	0	5	0	0	0	2
67	33	12	JEEP	91374	91174	1	1	9	0	0	0	2
212	33	12	JEEP	100274	91174	1	0	3	0	0	0	2
68	33	13	JEEP	91374	91174	1	0	4	0	0	0	2
213	33	13	JEEP	100274	91174	1	0	3	0	0	2	2
69	33	14	JEEP	91374	91174	1	1	3	0	0	0	2
214	33	14	JEEP	100274	91174	1	0	3	0	0	0	2
70	33	15	JEEP	91374	91174	9	0	1	0	0	4	2
215	33	15	JEEP	100274	91174	12	0	1	0	0	3	2
71	33	16	JEEP	91374	91174	1	0	1	0	0	1	2
216	33	16	JEEP	100274	91174	0	0	3	0	0	0	2
72	33	17	JEEP	91374	91174	2	0	4	0	0	0	2
217	33	17	JEEP	100274	91174	2	0	4	0	0	0	2
73	33	18	JEEP	91374	91174	1	0	3	0	0	0	2
218	33	18	JEEP	100274	91174	1	0	3	0	0	0	2
74	33	19	JEEP	91374	91174	2	0	3	0	0	0	2
219	33	19	JEEP	100274	91174	2	0	3	0	0	0	2
75	33	20	JEEP	91374	91174	1	1	7	0	0	0	2
220	33	20	JEEP	100274	91174	0	1	3	0	0	0	2
76	33	21	JEEP	91374	91174	5	0	3	0	0	0	2
221	33	21	JEEP	100274	91174	0	1	4	0	0	1	2
77	33	22	JEEP	91374	91174	7	2	1	0	0	2	2
222	33	22	JEEP	100274	91174	6	0	5	0	0	0	2
78	33	23	JEEP	91374	91174	1	0	6	0	0	0	2
223	33	23	JEEP	100274	91174	1	0	5	0	0	0	2
134	452	5	JEEP	91974	91174	6	0	4	0	0	11	[illegible]
269	452	5	JEEP	100274	91174	[illegible]	0	[illegible]	0	0	3	[illegible]
135	452	6	JEEP	91974	91174	4	1	7	0	0	0	2
270	452	6	JEEP	100274	91174	2	1	4	0	1	2	2
136	452	7	JEEP	91974	91174	12	0	4	0	0	4	2
271	452	7	JEEP	100274	91174	3	2	2	0	0	2	2

REM1

	TAPE	RUN	VEH	DATE	LEARN	TGT	TRK	WHL	RW	FW	G	A
137	852	8	JEEP	91974	91174	14	1	5	0	0	3	0
272	852	8	JEEP	100274	91174	9	1	3	0	0	4	0
138	852	9	JEEP	91974	91174	8	0	1	0	0	3	0
273	852	9	JEEP	100274	91174	1	0	2	0	0	2	0
139	852	10	JEEP	91974	91174	9	1	3	0	0	3	0
274	852	10	JEEP	100274	91174	6	0	5	0	0	2	0
140	852	11	JEEP	91974	91174	10	0	4	0	0	1	0
275	852	11	JEEP	100274	91174	5	0	4	0	0	4	0
141	852	12	JEEP	91974	91174	5	2	3	0	0	5	0
276	852	12	JEEP	100274	91174	2	2	3	1	0	5	0
142	852	13	JEEP	91974	91174	18	0	0	0	0	4	0
277	852	13	JEEP	100274	91174	15	0	0	0	2	3	0
143	852	14	JEEP	91974	91174	14	2	3	0	0	5	0
278	852	14	JEEP	100274	91174	10	3	4	0	0	6	0
279	852	15	JEEP	100274	91174	12	0	6	0	0	2	0
144	852	16	JEEP	91974	91174	16	0	4	0	1	0	0
179	843	1	JEEP	91674	91174	8	0	0	1	0	0	0
328	843	1	JEEP	100274	91174	8	0	0	0	0	0	1
180	843	2	JEEP	91674	91174	4	0	0	0	0	0	0
329	843	2	JEEP	100274	91174	4	0	0	0	0	0	0
181	843	3	JEEP	91674	91174	11	0	2	2	1	2	2
330	843	3	JEEP	100274	91174	14	0	1	3	1	0	3
182	843	4	JEEP	91674	91174	17	0	3	1	0	0	2
331	843	4	JEEP	100274	91174	22	0	2	1	0	0	2
183	843	5	JEEP	91674	91174	22	0	1	1	3	1	3
332	843	5	JEEP	100274	91174	19	0	0	0	1	0	2
184	843	6	JEEP	91674	91174	17	0	0	0	2	0	2
333	843	6	JEEP	100274	91174	22	0	0	1	2	0	1
185	843	7	JEEP	91674	91174	12	0	0	0	1	0	0
334	843	7	JEEP	100274	91174	9	0	0	0	1	0	0
186	843	8	JEEP	91674	91174	11	0	0	0	1	0	0
335	843	8	JEEP	100274	91174	11	0	0	0	2	0	0
187	843	9	JEEP	91674	91174	8	0	1	0	0	0	0
336	843	9	JEEP	100274	91174	8	0	1	0	0	0	0
337	843	9	JEEP	100274	91174	9	0	0	0	3	0	0
188	843	10	JEEP	91674	91174	13	0	0	1	3	0	2
189	843	11	JEEP	91674	91174	10	1	3	0	0	2	3
338	843	11	JEEP	100274	91174	6	1	0	0	0	1	0
						543	37	242	13	25	121	22
						543						
15	R1	2	KC135	91674	91174	1	1	0	0	4	0	0
351	R1	2	KC135	100374	91174	2	0	0	0	3	0	0
352	R1	3	KC135	100374	91174	5	0	0	0	1	0	0
16	R1	4	KC135	91674	91174	2	0	0	0	4	0	0
353	R1	4	KC135	100374	91174	3	1	0	0	2	0	1
17	R1	5	KC135	91674	91174	3	2	0	0	1	0	2
354	R1	5	KC135	100374	91174	3	1	0	0	1	1	0
18	R1	6	KC135	91674	91174	4	0	0	0	1	0	1
355	R1	6	KC135	100374	91174	4	0	0	0	3	0	0
19	R1	7	KC135	91674	91174	2	1	0	0	3	0	0
356	R1	7	KC135	100374	91174	2	1	0	0	3	0	0
20	R1	8	KC135	91674	91174	2	1	0	0	5	0	0

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	TAPE	RUN	VEH	DATE	REM1 LEARN	TGT	TRK	WHL	RW	FW	C	A
357	R1	8	KC135	100374	91174	5	0	0	0	4	1	0
21	R1	9	KC135	91674	91174	2	0	0	0	3	1	0
358	R1	9	KC135	100374	91174	6	0	0	0	5	0	0
22	R1	10	KC135	91674	91174	1	1	1	0	3	0	0
359	R1	10	KC135	100374	91174	2	0	0	0	5	0	0
23	R1	11	KC135	91674	91174	2	0	1	0	3	0	0
360	R1	11	KC135	100374	91174	5	0	0	0	4	0	0
24	R1	12	KC135	91674	91174	2	0	1	0	3	0	0
361	R1	12	KC135	100374	91174	2	0	1	0	3	0	0
25	R1	13	KC135	91674	91174	2	0	0	0	4	0	1
362	R1	13	KC135	100374	91174	4	0	0	0	5	0	0
26	R1	14	KC135	91674	91174	1	1	0	0	3	0	0
363	R1	14	KC135	100374	91174	2	1	0	0	4	0	0
						69	11	4	0	60	3	3
						69						
156	M16	14	M106	91374	91174	21	5	0	0	0	1	0
						21	5	0	0	0	1	0
						21						
315	M16	14	M106A	101274	91174	18	4	0	0	0	0	0
						18	4	0	0	0	0	0
						18						
157	M32	1	M48	91374	91174	16	2	0	0	0	1	0
280	M32	1	M48	101274	91174	13	2	0	0	0	2	0
158	M32	2	M48	91374	91174	8	0	0	0	0	2	0
281	M32	2	M48	101274	91174	9	0	0	0	0	1	0
159	M32	3	M48	91374	91174	13	1	0	0	0	0	0
282	M32	3	M48	101274	91174	13	1	0	0	0	0	0
160	M32	4	M48	91374	91174	7	0	0	0	0	0	0
283	M32	4	M48	101274	91174	7	0	0	0	0	0	0
161	M32	5	M48	91374	91174	11	0	0	0	0	0	0
284	M32	5	M48	101274	91174	11	0	0	0	0	0	0
						126	6	0	0	0	0	0
						12[illegible]						
116	B31	1	M577	91374	91174	12	5	0	0	0	2	0
291	B31	1	M577	101274	91174	11	5	0	0	0	2	0
117	B31	2	M577	91374	91174	6	3	0	0	0	4	0
292	B31	2	M577	101274	91174	8	3	0	0	0	2	0
120	B31	3	M577	91374	91174	5	5	0	0	0	1	0
293	B31	3	M577	101274	91174	5	4	0	0	0	3	0
121	B31	4	M577	91374	91174	8	6	0	0	0	0	0

	TAPE	RUN	VEH	DATE	REM1 LEARN	TGT	TRK	WHL	RW	FW	S	A
294	831	4	M577	100274	91174	4	6	Ø	Ø	Ø	Ø	[illegible]
122	831	5	M577	91374	91174	6	4	Ø	Ø	Ø	1	[illegible]
295	831	5	M577	100274	91174	4	5	Ø	Ø	Ø	1	[illegible]
123	831	6	M577	91374	91174	4	4	Ø	Ø	Ø	2	[illegible]
296	831	6	M577	100274	91174	3	4	Ø	Ø	Ø	2	[illegible]
124	831	7	M577	91374	91174	4	4	Ø	Ø	Ø	1	[illegible]
297	831	7	M577	100274	91174	4	4	Ø	Ø	Ø	1	[illegible]
125	831	8	M577	91374	91174	3	4	Ø	Ø	Ø	2	[illegible]
298	831	8	M577	100274	91174	4	4	Ø	Ø	Ø	2	[illegible]
126	831	9	M577	91374	91174	9	1	Ø	Ø	Ø	1	[illegible]
299	831	9	M577	100274	91174	9	2	Ø	Ø	Ø	1	[illegible]
127	831	10	M577	91374	91174	9	4	Ø	Ø	Ø	1	[illegible]
300	831	10	M577	100274	91174	9	4	Ø	Ø	Ø	Ø	[illegible]
128	831	11	M577	91374	91174	6	4	Ø	Ø	Ø	Ø	[illegible]
301	831	11	M577	100274	91174	6	3	Ø	Ø	Ø	1	[illegible]
129	831	12	M577	91374	91174	5	5	Ø	Ø	Ø	1	[illegible]
302	831	12	M577	100274	91174	6	3	1	Ø	Ø	1	[illegible]
303	831	13	M577	100274	91174	19	1	1	Ø	Ø	11	[illegible]
						169	97	2	Ø	Ø	43	[illegible]
						169						
						24Ø1	448	526	15[illegible]	238	462	81

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Appendix B

DETAILED RESULTS FROM "LIVE" EVALUATION AT EPG

In the following pages, the first column is an identification code for information retrieval purposes. The combination of TAPE and RUN specifies the exact location of the recorded run. The vehicle type is abbreviated in the VEH column and the evaluation date is given in the DATE column. LEARN refers to the generation date of the reference patterns under test. The remaining columns, TGT, TRK, WHL, RW, FW, G, and A, list the number of responses of each type output during the run.

EPG TEST

	LOC	RUN	VEH	DATE	LEARN	TGT	TRK	WHL	RW	FW	G	A	
50	EPG	1	2.5T	120974	111974	5	1	3	0	0	2	0	
51	EPG	2	2.5T	120974	111974	6	0	0	0	0	4	0	
52	EPG	3	2.5T	120974	111974	4	0	0	0	0	4	0	
53	EPG	4	2.5T	120974	111974	6	0	0	0	0	3	0	
54	EPG	5	2.5T	120974	111974	1	1	2	0	0	2	0	
55	EPG	6	2.5T	120974	111974	4	1	2	0	0	5	0	
56	EPG	7	2.5T	120974	111974	7	1	1	0	0	4	0	
41	EPG	1	2.5T	121074	111974	0	4	7	0	0	6	0	
42	EPG	2	2.5T	121074	111974	0	0	7	0	0	8	0	74%
43	EPG	3	2.5T	121074	111974	0	0	3	0	6	8	0	
44	EPG	4	2.5T	121074	111974	1	0	1	0	13	3	1	
45	EPG	5	2.5T	121074	111974	4	2	2	0	0	2	0	
46	EPG	6	2.5T	121074	111974	1	3	1	0	0	3	0	
47	EPG	7	2.5T	121074	111974	1	1	1	0	0	6	0	
48	EPG	8	2.5T	121074	111974	2	3	1	0	0	4	0	
49	EPG	9	2.5T	121074	111974	3	2	6	0	0	9	0	
						45	19	37	0	19	73	1	
31	EPG	1	5T	121074	111974	1	0	5	0	0	15	0	
40	EPG	10	5T	121074	111974	0	3	5	0	0	1	0	
32	EPG	2	5T	121074	111974	0	0	4	0	0	13	0	
33	EPG	3	5T	121074	111974	2	0	2	0	0	14	0	
34	EPG	4	5T	121074	111974	0	0	4	0	0	12	0	84%
35	EPG	5	5T	121074	111974	0	0	3	0	0	12	0	
36	EPG	6	5T	121074	111974	0	6	1	0	0	1	0	
37	EPG	7	5T	121074	111974	0	4	2	0	0	3	0	
38	EPG	8	5T	121074	111974	0	4	3	0	0	2	0	
39	EPG	9	5T	121074	111974	1	3	4	0	0	2	0	
						4	20	33	0	0	75	0	
11	EPG	1	HPC	120974	111974	2	6	0	0	0	4	0	
10	EPG	10	HPC	120974	111974	1	4	0	0	0	0	0	
12	EPG	2	HPC	120974	111974	2	3	0	0	0	5	0	
13	EPG	3	HPC	120974	111974	1	5	0	0	0	1	0	
14	EPG	4	HPC	120974	111974	3	2	1	0	0	1	0	96%
15	EPG	5	HPC	120974	111974	5	2	0	0	0	1	0	
16	EPG	6	HPC	120974	111974	1	2	0	0	1	2	0	
17	EPG	7	HPC	120974	111974	3	3	0	0	0	3	0	
18	EPG	8	HPC	120974	111974	3	2	0	0	0	2	0	
19	EPG	9	HPC	120974	111974	3	2	0	0	0	2	0	
						24	31	1	0	1	21	0	
21	EPG	1	JEEP	121074	111974	0	1	3	0	0	3	0	
20	EPG	10	JEEP	121074	111974	0	0	4	0	0	5	0	
22	EPG	2	JEEP	121074	111974	1	1	4	0	0	5	0	
23	EPG	3	JEEP	121074	111974	1	0	4	0	0	8	0	
24	EPG	4	JEEP	121074	111974	0	0	4	0	0	8	0	97%
25	EPG	5	JEEP	121074	111974	0	0	3	0	0	4	0	
26	EPG	6	JEEP	121074	111974	1	0	9	0	0	9	0	
27	EPG	7	JEEP	121074	111974	0	0	5	0	0	2	0	
28	EPG	8	JEEP	121074	111974	0	1	4	0	0	3	0	
29	EPG	9	JEEP	121074	111974	0	0	2	0	0	6	0	

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EPG TEST

	LOC	RUN	VEH	DATE	LEARN	TGT	TRK	WHL	RW	FW	S	A	
						3	3	42	0	0	53	0	
1	EPG	1	M48	120974	111974	0	8	0	0	0	2	0	
10	EPG	10	M48	120974	111974	0	5	0	0	0	1	0	
2	EPG	2	M48	120974	111974	3	5	0	0	0	0	0	
3	EPG	3	M48	120974	111974	2	7	0	0	0	0	0	
4	EPG	4	M48	120974	111974	1	7	0	0	0	1	0	
5	EPG	5	M48	120974	111974	0	7	0	0	0	2	0	98.5%
6	EPG	6	M48	120974	111974	3	4	1	0	0	1	0	
7	EPG	7	M48	120974	111974	2	5	0	0	0	0	0	
8	EPG	8	M48	120974	111974	2	3	0	0	0	3	0	
9	EPG	9	M48	120974	111974	1	4	0	0	0	1	0	
						14	55	1	0	0	11	0	
						90	128	114	0	20	233	1	

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